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Changing Climatic Scenarios: Role of Crop Growth Simulation Models

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Abstract

Crop growth simulation model is an efficient tool to predict the growth and yield of a crop. The models are good to simulate the effect of various crop management factors to obtain quick results and increase the efficiency of agronomic experiments in climate change conditions. The model has also been used for climate change impact on the soil N losses, like denitrification, volatilization, N_2O emission increased. This paper discusses the importance of crop growth simulation models applications and their future projections under changing climatic scenarios.

Keywords: Volatilization; Agronomic Experiments; Phenological Development; Phenophase.

Crop yield is invariably influenced by several factors like weather, soil type and its nutrient status, management practices and other inputs available. weather is the only environmental factor which influences the growth in every phenophase of the crop cycle. Its impact on morphology, development, biomass production and days to attain the phenophase is well established. The full genetic potential of the cultivar is only obtained only when an optimum climatic condition including other environmental factors is available. The optimum sowing time and selection of improved cultivars play a remarkable role in exploiting the yield potential of the crop under a particular agro climatic condition. It also governs the crop phenological development and the efficient conversion of biomass into economic yield. weather and climate are important factors in determining our day-today and long term activities. As weather assumes significance in nearly every phase of agricultural activity from the preparatory tillage to harvest and storage interfering with routine agricultural operations and plant protection measures, hence success or failure of farming is intimately related to the prevailing weather conditions (Araya, 2010). Climate has been changing in the last three decades and will continue changing regardless of any mitigation Strategy (Ramirez-Villegas, 2013). Agriculture is a climate-dependent activity and hence is highly sensitive to climatic changes and climate variability. Climate change is influencing the growing period of the crops, crop growth, arable land acreage, soil erosion, fertility and pests, diseases and weeds incidence.

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Model is a simplified description of a system to assist calculations and predictions (Loomis *et al.*, 1979). The relationship between weather and crop production has been understood through crop weather modeling and study on this aspect in a systematic manner started a century ago while in India it was initiated less than six decades ago (Aggarwal *et al.*, 2006 a). The understanding of the interactions between weather, soil, and management practices etc using simulation modelling will help in impact, adaption and vulnerability studies in agriculture. Specifically, a crop model can be described as a quantitative scheme for predicting the growth, development, and yield of a crop, given a set of genetic features and relevant environmental variables (Monteith, 1996). Crop growth simulation model is a very effective tool to predict the growth and yield of a crop (Banerjee *et al.*, 2014).Crop models can fulfill various requirements primarily to interpret experimental results and work as agronomic research tools for research knowledge synthesis. Lengthy, laborious and expensive field experiments, especially with a high number of treatments, can be pre-evaluated through a well-proven model to sharpen the field tests and to lower their overall costs (Whisler *et al.*, 1986). Another application of crop models is to use them as decision support tools for system (Pereira, 1998). Scientific modelling is also meant to be more mechanistic, based on laws and theory on how the system functions, while engineering modeling is meant to be functional, based on a mixture of well-established theory and robust empirical relationships, as termed by Addiscott and Wagenet (1985). Bhattacharya and Sastry (1999) evaluated the performance of three-crop growth models for dynamic simulation of soil water balance in the sandy loam soils cropped with oilseed *Brassica* and observed that the simulated root zone moisture from Campbell-Diaz model was more sensitive to stepwise changes in input parameters as compared to the O'Leary and SWASIM model. While calibrating these models during the post-rainy season of 1992-1993, the simulated profile moisture from the Campbell-Diaz and SWASIM models, on an average, did not deviate by more than ± 5% from the measurements except on one or two occasions whereas the O'Leary model gave slight overestimates up to seed filling stage and underestimates of the order of - 6% in the post-seed filling stage.

The crop model INFOCROP for potato, applied for increasing the efficiency of agronomic experiments in tropical environments over the period of 1976 to 1999 revealed a close agreement for simulated trends of phenological development, growth and tuber yield with the measured values within acceptable error. The model was found adequate to simulate the effect of various crop management factors to obtain quick results and increase the efficiency of agronomic experiments Singh *et al.* (2005 a). Panigrahi and Panda (2003) studied a simple soil water balance model to simulate the soil water content in the active root zone of mustard crop (*Brassica juncea*) as well as that the model was also tested with field experimental data of 2 years (1998 and 1999) under rain-fed (no irrigation) and irrigated conditions, found that the model satisfactorily simulated the soil water content in the active root zone of the crop on daily basis. Values of the mean absolute relative error (MARE) index between the observed and simulated soil water content of the rain-fed mustard in 1998 and 1999 were found to be 0.046 and 0.058, respectively, whereas for irrigated mustard, it was 0.051 in 1999. Prediction efficiency (PE) index was found to be 0.98, 0.97 and 0.97 for rain-fed mustard of 1998 and 1999 and irrigated mustard of 1999, respectively. Since the MARE index was low and PE index was high for both rain-fed and irrigated mustard, they concluded that the model could be used to simulate the soil water content in the active root zone of the crop.

On adaptation of the generic crop model INFOCROP for potato and applied it for increasing the efficiency of agronomic experiments in tropical environments over the period of 1976 to 1999. They reported a close agreement for simulated trends of phenological development, growth and tuber yield with the measured values within acceptable error. The model was found adequate to simulate the effect of various crop management factors to obtain quick results and increase the efficiency of agronomic experiments (Singh *et al.*,2005 a). Aggarwal *et al.* (2006 b) validated InfoCrop model for rice and wheat crops in contrasting agro-environments of tropics, sensitivity to the key inputs, and also illustrated two typical applications of the model, to quantify multiple pests damage through iso-loss curves and use of InfoCrop for analyzing the trade-offs between increasing crop production, agronomic management strategies, and their global warming potential.

The results of field experiments and use of simulation tools to understand the dynamics of soil N balance and relate growth and yield of rice under varying nitrogen inputs showed that the simulated results of InfoCrop model matched well with the observed values for growth and yield of rice and seasonal nitrogen uptake. The model was also used for climate change impact analysis and revealed that when temperature increased, the soil N losses, like denitrification, volatilization, N_2O emission increased, whereas grain and biomass yields was found decreased (Ebrayi *et al.*,2007). The simulated impact of elevated CO_2 and temperature on rice yield in eastern India by using the ORYZA1 and the INFOCROP rice models shows that for every 1°C increase in temperature, ORYZA1 and INFOCROP rice models predicted average yield changes of -7.20 and -6.66%, respectively, at the current level of CO_2 (380 ppm). However, increases in the CO2 concentration up to 700 ppm led to the average yield increases of about 30.73% by ORYZA1 and 56.37% by INFOCROP rice. Results suggest that the limitations on rice yield imposed by high CO_2 and temperature can be mitigated, at least in part, by altering the sowing time and the selection of genotypes that possess higher fertility of spikelets at high temperatures (Krishnan *et al.* , 2007).

Naresh *et al.* (2008) calibrated and validated InfoCrop-coconut model with data compiled from published studies comprising many physiological, agronomical and nutritional experiments conducted between 1978 and 2005 in diverse geographic locations throughout India. Simulated trends in phenological development, total dry mass and its partitioning and nut yield agreed closely with observed values with 15% error in a few cases. InfoCrop-coconut was found suitable for the use to increase the efficiency of agronomic experiments designed to aid coconut crop management.

Haris *et al.* (2010) evaluated the effect of projected change in climate on rice growth and yield through INFOCROP model by conducting an experiment during *kharif* from 2006 to 2008 at Patna, Bihar. Using the factors from HADCM3 (Hadley Centre Coupled Model ver.3) GCM (General Circulation Model) predictions, rice yield was simulated for future scenarios. An increase in rice yields for 2020 scenario to the tune of 2.7% decrease upto 0.3% for 2050 and a decline of 31.3% in 2080 from baseline with the current agronomic practices was predicted. The simulation results also revealed that an increase in minimum temperature in future could be more detrimental for long duration rice variety (MTU-7029) in terms of yield.

The role of climate extremes in climate change impact assessment of typical winter and summer Mediterranean crops by using Regional Circulation Model (RCM) outputs as drivers of a modified version of the CropSyst model has been studied. The climate change effects were investigated on sunflower (*Helianthus annuus* L.) and winter wheat (*Triticum aestivum* L.) development and yield under the A2 and B2 scenarios of the IPCC Special Report on Emissions Scenarios (SRES) including direct impact of extreme climate events (i.e. heat stress at anthesis stage). The increase in both mean temperatures and temperature extremes under A2 and B2 scenarios (2071–2100) resulted in: a general advancement of the main phenological stages, shortening of the growing season and an increase in the frequency of heat stress during anthesis with respect to the baseline (1961–1990). It was also concluded that winter and summer crops may possess a different fitting capacity to climate change. Sunflower, cultivated in the southern regions of the Mediterranean countries, was more prone to the direct effect of heat stress at anthesis and drought during its growing cycle and resulted in severe yield reduction. In contrast, the lower frequency of heat stress and drought allowed the winter wheat crop to attain increased yields with respect to the baseline period (Moriondo *et al.* , 2011).

The simulated results of DSSAT Cropping System Model (CSM-CROPGRO) for rapeseed (*Brassic napus*) under Mediterranean conditions. Phenology, growth, and partitioning were evaluated using experimental data from two locations of Sardinia (Italy) for 2007 and 2008 for rapeseed revealed satisfactory predictions of phenology, growth, and yield of rapeseed and hence concluded that the CSM-CROPGRO model could be used for simulation of rapeseed production in Mediterranean environments (Deligios *et al.*,2013).

Soora *et al.* (2013) investigated a simulation analysis using the InfoCrop-rice model to quantify impacts and adaptation gains, as well as to identify vulnerable regions for irrigated and rainfed rice cultivation in future climates in India. Climates in A1b, A2, B1 and B2 emission scenarios as per a global climate model (MIROC3.2.HI) and a regional climate model (PRECIS) were considered for the study. As par the simulated results on an aggregated scale, the mean of all emission scenarios indicate that climate change is likely to reduce irrigated rice yields by ~4 % in 2020 (2010–2039), ~7 % in 2050 (2040–2069), and by ~10 % in 2080 (2070–2099) climate scenarios. On the other hand, rainfed rice yields in India are likely to be reduced by ~6 % in the 2020 scenario, but in the 2050 and 2080 scenarios they are projected to decrease only marginally (<2.5 %).

Validation of impact of projected climate change on yields of soybean InfoCrop model for 20 years (1989-2008) to assess impacts of the projected climate change on soybean production reveals that The Root Mean Square Error (RMSE) values were 8.8 days and 190.4 kg/ha for days to maturity and crop yield between simulated and observed yields of five years (2004-08) under two sowing environments. The elevated levels of 50 and 100 parts per million (ppm) carbon dioxide (CO_2) increased soybean yield by 5.0 to 10.2%. The projected yield losses due to elevated levels of temperature by 1 and 2°C alone ranged between 1.3 to 3.5 and 4.5 to 6.0 percent respectively, for all planting windows. The elevated temperature of 1°C coupled with 50 ppm elevated level of carbon dioxide (420 ppm) showed increase in yield up to 4.9 percent with shortened average growing period up to 2 days. The further rise of temperature to 2°C with 50 ppm elevated level of carbon dioxide caused increase in simulated yield up to 2.3 percent in simulations of 1989-2008 compared to control conditions. Similarly, 100 ppm elevated level of carbon dioxide with 1°C rise in temperature caused increase in yield between 8.8 to 10.2 percent in all planting windows whereas it was 3.1 to 3.9 percent lesser in 2°C rise in temperature with 100 ppm elevated level of carbon dioxide with compared to 1°C rise in temperature. The climatic grid of 10 percent reduction in rainfall from recent decade 1998-2008 showed small decrease in yield but yield increase of 5.2 to 8.5 percent was observed when coupled with 50 ppm elevated carbon dioxide and 1°C rise in temperature. Hence rise of temperature with elevated carbon dioxide in general increase the yield in region (Ranbir *et al.*, 2014).

It has been opined that the climate change believed to affect agriculture by inducing changes on farmer behaviour, quantity, quality, cost of production; changes in production, consumption, prices, and trade patterns; and the changes in market responses at global and local levels. These changes not only depend on the domestic and global adaptive capacity, the economic impacts also vary by region, sector, and the stakeholder groups. The adverse impacts are likely from the increased frequency of extreme weather, floods and droughts and submergence of coastal areas due to the rise in sea levels and extreme climate variability. The mountain regions are vulnerable to climate change and it would have direct impacts on livelihoods as most of the economic and livelihood sectors are vulnerable to the impacts of climate change (Sharma and Dobriyal , 2014).

References

1. Addiscott, T.M., and Wagenet, R.J. Concepts of solute leaching in soils: A review of modeling approaches. *J. Soil Sci*. 1985; 36: 411–424.
2. Aggarwal, P.K., Kalra, N., Chander, S. and Pathak, H. a. InfoCrop: A dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. I. Model description. *Agricultural Systems*. 2006; 89: 1–25.
3. Aggarwal, P.K., Banerjee, B., Daryaei, M.G., Bhatia, A., Bala, A., Rani, S., Chander, S., Pathak, H. and Kalra, N. InfoCrop: A dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. II. Performance of the model. *Agricultural Systems*. 2006b; 89: 47–67.
4. Araya, A. Simulating yield response to water of Teff (Eragrostis tef) with FAO's Aqua Crop model. *Field Crops Research*. 2010; 116: 196–204.
5. Banerjee, S., Das, S., Mukherjee, A., Mukherjee, A. and Saikia, B. Adaptation strategies to combat climate change effect on rice and mustard in Eastern India. *Mitig Adapt Strateg Glob Change*. 2014; 1-10.
6. Bhattacharya, B.K. and Sastry, P.S.N. Comparative evaluation of three-crop growth models for the simulation of soil water balance in oilseed Brassica. *Agricultural Water Management*. 1999; 42: 29-46.
7. Deligios P. A.; Farci, R.; Sulas, L.; Hoogenboom, G. and Ledda, L. Predicting growth and yield of winter rapeseed in a Mediterranean environment: Model adaptation at a field scale. *Field Crops Research*. 2013; 144: 100–112.
8. Ebrayni, K. N., Pathak, H., Kalra. N., Bhatia, A. and Jain, N. Simulation of Nitrogen Dynamics in Soil Using Infocrop Model. *Environ Monit Assess*. 2007; 131: 451–465.
9. Haris, A.A., Biswas, S. and Chhabra,V. Climate change impacts on productivity of rice (*Oryza sativa*) in Bihar. *Indian Journal of Agronomy*. 2010; 55(4): 295-298.
10. Krishnan, P., Swain, D.K., Bhaskar, B. C., Nayak, S.K. and Dash, R.N. Impact of elevated CO_2 and temperature on rice yield and methods of adaptation as evaluated by crop simulation studies. *Agriculture, Ecosystems and Environment*. 2007; 122 : 233–242.
11. Loomis, R.S., Rabbinge, R. and Ng, E. Explanatory models in crop physiology. *Annual. Rev. Plant Physiology*. 1979; 30: 339–367.
12. Monteith, J.L. Toward a Combined Seasonal Weather and Crop Productivity Forecasting System: Determination of the Working Spatial Scale. *Journal of Applied Meteorology*. 1996; 42(2): 175–192.
13. Sharma, P. and Dobriyal, P. Climate Change and Agricultural Sector in Uttarakhand. *Journal of Studies in Dynamics and Change*. 2014; 1(1): 6-14.
14. Whisler, F.D., Acock, B., Baker, D.N., Fye, R.E., Hodges, H.F., Lambert, J.R., Lemmon, H.E., McKinion, J.M. and Reddy, V.R. Crop simulation models in agronomic systems. *Adv. Agronomy Journal*. 1986; 40: 141–208.
15. Soora, N.K., Aggarwal, P.K., Saxena, R., Rani, S., Jain, S. and Chauhan, N. An assessment of regional vulnerability of rice to climate change in India. *Climatic Change*. 2013; 118: 683–699.
16. Singh, J.P., Govindakrishnan, P.M., Lal, S.S. and Aggarwal, P.K. Infocrop-potato: a simulation model for growth and yield in tropics and Subtropics. SWCACIP, New Delhi, Newsletter. 2005a; 9(1): 1-2.
17. Ramirez-Villegas, J., Jarvis A., and Läderachd P. Empirical approaches for assessing impacts of climate change on agriculture: The EcoCrop model and a case study with grain sorghum. *Agricultural and Forest Meteorology*. 2013; 170: 67–78.
18. Naresh, S.K., S.N., Bai, K.V.K., Rajagopal, V., and Aggarwal P.K. Simulating coconut growth, development and yield with the InfoCrop-coconut model. *Tree Physiology*. 2008; 28: 1049–1058.
19. Panigrahi, B. and Panda, S.N. Field test of a soil water balance simulation model. *Agricultural Water Management*. 2003; 58: 223–240.
20. Pereira, L.S., Allen R., Raes D. and Smith M. 1998. Crop evapotranspiration guidelines for computing crop water requirements. *FAO Irrigation and Drainag*. 1998; 56.
21. *Rana R.S., Navell Chander, Rohit Sharma, Ruchi Sood, J D Sharma.* Modeling impacts and adaptations of climate change on soybean (glycine max) production in Himachal Pradesh, India. *Indian J. Agric. Science*. 2014; 84(10): 54-58.
22. Rabiee, M., Karimi, M.M. and Safa, F. Effect of planting dates on grain yield and agronomical characters of rapeseed cultivars as a second crop after rice. *Iranian J. of Agric. Sci*. 2004; 35(1): 177-187.